

**SOLAR SYSTEM TESTS OF GRAVITATIONAL THEORIES**

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Final Report

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Einstein's theory of general relativity is the basis for our understanding of the large-scale behavior of the universe, including the existence and properties of black holes. It is therefore important to establish the limits of validity of the theory on all relevant scales. Our efforts have been focused on tests of gravitational theory based on observations of the motions of solar-system objects, since the solar system is the nearest and most accessible large-scale "laboratory" where relativistic behavior is discernible. For this purpose, we analyze the behavior of the propagation of light, of the trajectories of the Moon and planet, and of gravitational and atomic clocks. Our goal is to detect departures from the standard model or to place increasingly stringent limits on such departures. In pursuit of that goal, we have added to our set of data, including several thousand radar ranging measurements to points on the surface of Mercury. We have also extended our set of lunar laser ranging (LLR) data and acquired additional time-of-arrival data for pulses from the millisecond pulsar PSR 1937+21.

Making use of the enhanced data set, we recently obtained a new bound on the annual variation of the gravitational constant at the level of one part in  $10^{11}$ . Essentially, this is a constraint on variations in the relative rates of gravitational and atomic clocks. The two primary gravitational clocks tested by our analysis are the Earth-Moon-Sun system and the Mars-Sun-Earth system, and the main contributing sets of data are the LLR and Viking Lander ranges, respectively. Each system is subject to separate perturbations that tend to mimic the sought-for effect, namely, the tidal deceleration of the Moon's orbit and the long-term perturbations of Earth and Mars due to asteroids; the simultaneous analysis of both systems gives a more robust determination than either one alone. Our result was presented at the 1993 meeting of the AAS Division on Dynamical Astronomy (Chandler *et al.*, 1993), and is being prepared for publication along with other results, including our recent bound of one part in  $10^3$  on the value of  $\eta$ , Nordtvedt's parameter of a violation of the Principle of Equivalence. For fully conservative theories of gravitation, in the absence of preferred-frame effects, the value of  $\eta$  is simply a linear combination of the Eddington-Robertson parameters  $\beta$  and  $\gamma$ :  $4\beta - \gamma - 3$  (Will, 1981).

We succeeded in porting our software (PEP) from the mainframe environment, where it was originally developed and where it ran for about 25 years, to a newer, and far cheaper, desk-top workstation. The inevitable small differences in hardware, operating systems, and compilers produced many "discrepancies" in the numerical results from our standard test suite for PEP, and it required a good deal of checking to become confident that the differences were all negligible. During an interim period, we derived results in parallel in both environments, verifying that the workstation results are reliable.

## References

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